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8. PERFORMANCE AND MISSIONS

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INTRODUCTION

The purpose of this paper is to discuss propulsion requirements for accomplishing specific missions, to examine the effect of component trends on vehicle design using the information provided by the preceding papers, and to focus attention on problems where research emphasis is needed.

The missions and the propellant combinations considered in the analysis are as follows:

Missions:

Surface-to-surface
Earth satellite
Moon orbits

Propellants:

RP-1 - oxygen
Hydrazine-fluorine
Hydrogen-fluorine
Present solid
Future solid

The present and the future solid propellants were assumed to have a sea-level specific impulse of 240 and 270 pound-seconds per pound, respectively. Other propellants of current interest not considered in this analysis are ammonia-fluorine and hydrogen-oxygen. The performance of ammonia-fluorine is similar to that of hydrazine-fluorine, and the trends of hydrogen-oxygen can be deduced from those shown for hydrogen-fluorine.

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COMPONENT WEIGHT SELECTION

Weight Designations

In order to calculate vehicle performance, it was necessary to assign specific powerplant weights and specific body weights for each propellant combination. Figure 1 is a schematic drawing of a rocket missile showing the weight designations for both liquid and solid propellants. The nose contains the load, which comprises the payload and such fixed weights as guidance mechanisms, powerpacks, and so forth. The rest of the missile is the propulsion system consisting of propellants and structure.

4793-I

For liquid-propellant systems the structure is divided into the body and the powerplant. The body consists of such items as tanks, pressurization (tanks, gas, and system), lines, baffles, launching and separation gear, and residual fluids. The body weight is considered proportional to propellant weight. The powerplant consists of thrust chamber (injector, chamber, nozzle), turbopump (turbine, two pumps, gas generator, lubrication system), engine controls (gimbaling, propellant utilization, starting and shutdown systems) mounting frame, and residual fluids. The powerplant weight is considered proportional to thrust, as indicated in the figure.

The structure of the solid-propellant engine is not subdivided. It consists of such items as case, insulation, inhibitor, head closure, launching and separation gear, thrust reversal, nozzle, engine controls, mounting, and residual propellant, if any. These items are expressed as a function of propellant weight.

When the relations between thrust, propellant weight, and gross weight are known for a particular mission, the body and powerplant weights can be combined into a single structure weight and expressed as a function of propellant or gross weight. The ratio used to compare vehicle performance with different propellants and missions is the ratio of gross weight to load.

Flight Equation

The most important factors in rocket vehicle performance are related by the equation

$$\Delta V = I_S\, g \ln\left(\frac{1}{\frac{W_L}{W_G} + \frac{W_S}{W_G}}\right) - \Delta V_l \qquad (1)$$

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The first term shows that velocity is a function of specific impulse and the ratios of load to gross weight and structure to gross weight. The second term accounts for velocity losses from gravitational pull (comparatively large for first-stage operation) and drag (comparatively small). These losses are considered in the analyses of this paper.

Specific Impulse

4793-I

The importance of specific impulse is obvious. The specific impulse is not, however, a fixed value for a propellant combination, but depends on combustion-chamber pressure, altitude, and exhaust-nozzle design.

Altitude effect. - The theoretical specific impulse of a rocket engine with a fixed-nozzle area ratio of 13:1 (selected for the booster rockets) is shown as a function of altitude in figure 2. The remarkable change in specific impulse occurs at low altitudes. The specific impulse can be increased slightly at high altitude by increasing the area ratio of the nozzle but only at the expense of decreasing specific impulse in the low-altitude region.

Second- and third-stage engines usually fire into a nearly perfect vacuum. Consequently, the nozzles for these engines are enlarged to an area ratio of 50:1 to take advantage of the increase in specific impulse. On current ICBM missiles, these area ratios are 8:1 for the first stage and 25:1 for the second.

Efficiency. - The specific impulse also depends on the efficiency of conversion of chemical potential energy to heat. An over-all specific impulse of 90 percent of the theoretical specific impulse was assumed for these engines with a fixed-nozzle area ratio at each point along their flight path. The effective specific impulse is, of course, an integrated result.

The specific impulse values assumed in this analysis for RP-1 - O_2 in both the first- and the second-stage engines are about 15 units higher than those used in current missiles. This is partly due to the bigger nozzles, but primarily due to the higher over-all conversion efficiency of 90 percent which was assumed. NACA experiments with engines of 200 to 5000 pounds thrust indicate the 90-percent value is feasible. A 1000-pound-thrust engine with a 50:1 area-ratio nozzle was fired into a partial vacuum and gave a specific impulse of over 300 pound-seconds per pound with RP-1 - O_2.

Weight Ratios

The ratio W_L/W_G in equation (1) is directly affected by the other ratio W_S/W_G. A pound taken from the structure can be added to the

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payload without affecting the flight trajectory. As previously pointed out, the structure factor includes two terms. On the basis of information given in the preceding paper and estimates of accessory weights of current vehicles, estimates were made for the powerplant weight in terms of thrust and for the body weight in terms of propellant weight.

Powerplant specific weight. - The powerplant specific weights are given in table I.

TABLE I. - POWERPLANT SPECIFIC WEIGHTS

Propellants	Propellant mixture, % fuel	W_{pp}/F	
		Stage 1	Stages 2 and 3
RP-1 - O_2	30	0.009	0.011
N_2H_4-F_2	30	.009	.011
H_2-F_2	8	.010	.012

The propellant proportions shown in percent fuel are used in the analysis; the bulk densities are 65, 82, and 36 pounds per cubic foot, respectively. The specific engine weights for first-stage engines using RP-1 - O_2 and N_2H_4-F_2 were assumed to be the same. The second- and third-stage engines were assumed to be heavier because they use more elaborate controls, such as propellant utilization devices. These weights are about one-third less than those of current engines. The hydrogen-fueled powerplant was assumed to be heavier than the others because of added turbopump weight which results from the low bulk density of the propellants. More recent estimates of the turbopump weight of a hydrogen-fluorine rocket indicate that the powerplant weights given for the hydrogen-fueled engines are conservative. (See previous paper by A. Ginsburg.)

No separate powerplant weight was considered for the solid-propellant engines.

Body specific weight. - The body specific weights, that is, the body weight per pound of propellant, are shown in table II.

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TABLE II. - BODY SPECIFIC WEIGHTS

Propellants	W_B/W_P	
	Stage 1	Stages 2 and 3
RP-1 - O_2	0.04	0.06
N_2H_4-F_2	.04	.06
H_2-F_2	.06	.09
Solid (present)	.10	.10
Solid (future)	.08	.08

4793-I

The body weight of solid-propellant engines is the structure weight of the vehicle or of its stage. The increased body weights for hydrogen-fueled systems are again a consequence of the low bulk density. The specific weights differ for different stages because of added support required for bending stresses in the second- and third-stage frame. The bending stresses are produced during gimbaled firing of the first-stage engine.

These assumed body weights apply only for large vehicles and are, of course, somewhat arbitrary. A body factor of only one significant figure is shown because more accurate numbers are not justified. The values for RP-1 - O_2 and present solids compare favorably with values for current advanced missiles.

A typical split of structure weight between body and powerplant is shown in figure 3. Most of the weight is in the body. Later the effects of changing the values of component weights will be considered.

SURFACE-TO-SURFACE MISSIONS

Typical trajectories for surface-to-surface missions are shown in figure 4. The IRBM, Intermediate Range Ballistic Missile, has a range of 1500 nautical miles and requires a velocity at thrust termination of about 14,000 feet per second and an angle of 35° with reference to the earth. The ICBM, Inter-Continental Ballistic Missile, has a range of about 5500 nautical miles and requires a velocity of about 23,000 feet per second and an angle of about 22° with respect to the earth. At burnout it is about 100 miles high and 300 miles distant from the launching point.

IRBM Missions

The effect of the selected propellants on the gross weight of an IRBM missile for a useful load of 5000 pounds is shown by the bar diagram

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of figure 5. For RP-1 - O_2, a gross weight of approximately 60,000 pounds is required. This can be compared with a gross weight of 110,000 pounds for a current vehicle using RP-1 - O_2, as indicated by the dashed bar. The difference in the gross weights is due to the ratio of structure to gross weight and to the specific impulse assumed. The structure factor used for the IRBM in the design studies was somewhat lower than current practice and can be considered to be an advance in the present state of art for this mission. In addition, the specific impulse used in the design calculations was about 5 percent higher than that being developed in current engines. 4793-I

With present-day solid propellants, a single-stage vehicle requires a gross weight of about 220,000 pounds; by designing for a two-stage missile, however, the gross weight is reduced to about one-half this weight. The anticipated performance of future solid propellants results in a substantial reduction in the gross weight, for both one- and two-stage missiles. The gross weight required for a storable liquid-propellant combination $N_2H_4 + ClF_3$ is included for comparison. The gross weight is about the same as for RP-1 - O_2 for a single-stage missile. A two-stage missile will weigh about 20 percent less.

Reducing the load results in a general reduction in the gross-weight requirements. A load of 2000 pounds would require about 40 percent of the gross weights of figure 5. For the reduced load, the RP-1 - O_2 system would weigh about 20,000 pounds, and a two-stage present-day solid-propellant system would weigh around 30,000 pounds. This last value compares well with the gross weight expected for a two-stage solid-propellant missile currently under development.

High-energy liquid propellants were not considered for this mission because they are not needed. Propellants would be selected on the basis of their performance, cost, availability, and ease of handling and storage. The safe transportation and readiness of missiles using solid propellants seem to make them well suited for this mission.

The performance and reliability of small-solid-propellant engines and their handling ease are well established; these remain to be proved for large-solid-propellant engines. At present the large-solid-propellant engines are limited to fairly narrow temperature limits and there are other problems to be solved, such as transition from normal burning to detonation, thrust termination, and thrust vector control.

ICBM Missions

Typical ICBM. - A similar comparison of gross weights of the ICBM mission for a load of 5600 pounds is shown in figure 6. The gross weight for the RP-1 - O_2 two-stage vehicle is about 165,000 pounds. A current two-stage ICBM missile using RP-1 - O_2 weighs 220,000 pounds, as indicated by the dashed bar. The difference in gross weight is due primarily to the difference in specific impulse of the current engine and that assumed in the analysis.

The high performance of the N_2H_4-F_2 propellant combination results in a single-stage missile weighing about the same as the two-stage RP-1 - O_2 missile. The use of H_2-F_2 gives the minimum-gross-weight missile.

For present-day solid propellants, the gross weight of a two-stage missile is about 300,000 pounds, but decreases appreciably when three stages are used. The use of future solid propellants would result in considerable weight decrease. The gross weight of a future solid-propellant two-stage missile is about the same as the current RP-1 - O_2 missile, and a three-stage unit will reduce the weight about 30 percent further.

The gross weight can generally be reduced by adding more stages but will eventually level off or even rise as many stages are added because the structure weight of upper stages must be increased for joining and separation devices as well as for increased moments from changes in the thrust vector. The optimum number of stages depends on more detailed design considerations than are used in this analysis.

Alternate ICBM trajectories. - High-energy propellants could be used to decrease weight for ICBM missions. They could also be used to increase velocity to perform other ICBM missions. Figure 7 shows two such alternate trajectories. The missile could be lofted on a high trajectory to get a steeper angle of re-entry, for instance 47°, to improve accuracy. This requires about 3000 feet per second more velocity than the original trajectory. Or, for strategic purposes, a missile could be launched from the opposite side of the continent and go the long way to the target. Here again, the velocity requirement is greater - about 28,500 per second.

Accuracy of alternate trajectories. - There are a number of factors that will determine the accuracy and effectiveness of missiles on these trajectories: accurate measurement of the vector velocity and position at burnout, controlled fast thrust-cutoff, aerodynamic forces, and average winds on re-entry. There are also uncontrolled, indeterminate effects, such as the random winds on re-entry and mapping uncertainties. Most of these sources of error are reduced by the lofting of the trajectory.

Figure 8 shows the requirements for velocity control at burnout at an altitude of 100 miles, neglecting the effects of the earth's rotation. The effect of velocity error (ft/sec) on miss distance (miles) is plotted against the burnout velocity for lines of constant range. The IRBM on the 1500-nautical-mile line is shown at the point of minimum burnout velocity; the miss distance due to velocity error is 0.2 mile per ft/sec. Only small improvement in accuracy would be gained for the IRBM by increasing the burnout velocity.

The ICBM for minimum burnout velocity has an error of 1.1 mile per ft/sec at a path angle of 22°. If the angle is increased, the error would decrease along the curve at the expense of increased burnout velocity. At an angle of 47°, the error can be reduced by half (to 0.5 mile per ft/sec) but at the expense of a 3000 ft/sec increase in burnout velocity. 4793-I

For the backside ICBM (range of 14,400 nautical miles), the error is reduced as the velocity increases beyond satellite velocity and as the corresponding path angle increases. The point shown is for an angle of 15°; the error is 1.3 miles per ft/sec. This missile would require a burnout velocity of 28,400 ft/sec, or 5,400 ft/sec more than the conventional ICBM.

Other control factors are also improved by the lofting technique. The problems of fast thrust-cutoff time and altitude measurement are reduced in about the same manner as the velocity-measurement problem shown in figure 8. One parameter, that of path angle at burnout, is adversely affected by lofting. In figure 9 the requirements for the measurement of path angle at burnout are plotted for the four ballistic missiles. The effect of such angle error on miss distance is given in miles per minute of angle error. The missiles designed for minimum burnout velocity would be relatively insensitive to this error. If the ICBM (5500 nautical mile range) is lofted to 47°, the error would be 2 miles per minute angle. For the backside ICBM, the error is decreased for higher velocities and higher angle; at the point of burnout velocity used before, the error is 7 miles per minute angle error. These severe requirements on path-angle measurement are somewhat alleviated by the fact that the path angle is almost constant along a large part of the burning trajectory, and dynamic effects are small. The velocity, however, is continuously increasing at a high rate and must be measured instantaneously as well as very accurately.

<u>Accuracy at re-entry</u>. - Changing the trajectory, and therefore the path angle, affects the accuracy at re-entry. Consider the effect of winds over the target area. Because of aerodynamic heating, the nosecone may be designed to slow down appreciably on re-entering the atmosphere, which makes it subject to deviations by the winds. The average wind (if known) can be included in guidance, but the random winds cannot. Figure 10 shows the resulting possible dispersion on re-entry for the 5500-nautical-mile ICBM with estimated random winds. The standard deviation of miss distance in miles is plotted against the re-entry path angle in

degrees. For each path angle there is a coresponding re-entry velocity. These re-entry angles and velocities are almost equal to those at burnout. The lines are for constant values of weight-drag ratio (W/C_DA). Lofting can be used to decrease the dispersion due to the random winds. For example, for a weight-drag ratio of 100, which is approximately that of some present designs, the ICBM for minimum burnout velocity would have a dispersion of 1.2 mile. If the 47° loft angle is used, requiring an increase in velocity of 3000 feet per second, dispersion is reduced to 0.9 mile.

The lower drag nosecones being considered (W/C_DA of 500 or even 1000) are less affected by the winds, but they show much greater percentage improvement when lofting is used. For W/C_DA of 500, the dispersion can be reduced by a factor of 3.

All of the error factors that have been mentioned might be partially compensated by the use of terminal guidance; even so, it may be necessary to minimize the need for such compensation.

Excess velocity for ICBM missions. - The possibility of obtaining greater velocities than are now available in the ICBM by using high-energy propellants was investigated. The gross weight of the missile was assumed to be 220,000 pounds and the load 5600 pounds, as shown in figure 11. The excess velocity available from the RP-1 - O_2 propellant is about 3500 feet per second. For N_2H_4-F_2, the excess velocity is about 6400 feet per second and for the high-performance H_2-F_2 combination, about 9600 feet per second.

Excess velocity can also be obtained with the future solid propellant. A two-stage missile will provide excess velocity of about 2800 feet per second and a three-stage missile, approximately 4700 feet per second.

Excess velocities could be used for maneuvering an ICBM. After-all, a ballistic missile is really helpless after burnout. Perfection of an interceptor missile could make this weapon not nearly so effective as it is now considered. Figure 12 illustrates the requirements on excess impulse Δv for such maneuverability. A typical turn from the ballistic trajectory is shown, turning through an angle α. The Δv required to make this turn is approximately equal to the product of the angle of turn and the velocity.

Two maneuvers are shown using such a turn. For case 1, a single missile can threaten a region of target areas. By beginning the turn 1000 miles from impact, a line of 300 miles at the target can be covered if the missile is carrying fuel with a mass-ratio equivalent to a Δv of 7000 feet per second. This maneuver in three dimensions covers a

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region of about 140,000 square miles, an area three times greater than the state of Ohio. For this maneuver the ratio of distances is almost independent of how fast the excess Δv is used. For the case shown, a 1-g normal acceleration is used. The dispersion would improve somewhat if higher normal accelerations were used.

The second case is a maneuver turning away from the target direction and then approaching at a different angle. For a turn angle of 6°, an excess Δv of 7000 feet per second is required. The distances required for this maneuver depend on the normal acceleration used. For example, if a 5-g normal acceleration is used, the maneuver could start 200 miles from impact, and the maximum deviation from the ballistic path would be about 5 miles. 4793-I

The effectiveness of this kind of versatility built into the missile will, of course, depend on the intelligence and maneuverability of any interceptor missiles, as well as the other strategic and perhaps psychological factors involved.

Summary of Surface-to-Surface Missions

Solid propellants show promise for IRBM missions and lightly-loaded ICBM missions. High-energy liquids and solids offer weight savings for ICBM missions or, alternatively, higher velocities can be obtained and used for alternate trajectories for advantages of accuracy, surprise, or maneuverability. The choice of propellants will depend not only on the mission, but also on such other factors as readiness, mobility, size, and handling and operation problems.

EARTH SATELLITES

Guidance Requirements

Earth satellite orbits are shown in figure 13. A typical trajectory for launching a two-stage earth satellite into the orbit is shown in figure 14. The first-stage rocket boosts the vehicle to approximately 100 miles altitude and then a long coast puts the satellite into the orbital altitude of 300 miles. Then, the second stage fires and accelerates the satellite to the required orbital velocity of 25,000 feet per second.

The guidance requirements for a circular satellite orbit are shown in figure 15. In the sketch, the dotted circle is the reference desired circular orbit. If there is an error in angle and perhaps velocity at burnout, the actual orbit will be an ellipse whose height will deviate from the height at burnout, having a maximum positive deviation at apogee and a maximum negative deviation at perigee.

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The plot shows the maximum velocity error that can be tolerated for each such maximum allowable deviation and angle error. For a maximum deviation of 100 miles, an expected angle error of 1° would require velocity control at burnout to within 80 feet per second. This requirement is considerably less stringent than that for the ICBM. In fact, if the satellite carried ICBM quality guidance equipment, the maximum deviation could be kept within about 1 mile.

4793-I

Weight Comparisons

Figure 16 shows the gross weight - load ratio required for this mission for the propellant combinations selected. The heaviest of the two-stage vehicles is for the RP-1 - O_2 combination. It would take about 66 pounds of gross weight for every pound of load. The calculations showed that the present solid propellants would require at least three stages to put such a vehicle into its orbit. A satellite could be established with a future solid-propellant two-stage vehicle. The gross weight - load ratio for the future solid propellant appears to be as good as that of the RP-1 - oxygen vehicle. The lightest vehicle is the one with the hydrogen-fluorine propellant system. For this combination only 20 pounds of gross weight are required for every pound of load.

Also shown in figure 16 is the gross weight - load ratio for a satellite vehicle comprising an RP-1 - O_2 first stage and a H_2-F_2 second stage. Considerable weight saving over RP-1 - O_2 in both stages can be obtained by using high-energy propellants in the second stage.

Volume Comparisons

Figure 17 indicates the total propellant volume as a measure of the over-all bulk of the vehicle. Also indicated in figure 17 are the gross weights of such vehicles for a load of 20,000 pounds. The RP-1 - O_2 combination would produce the largest bulk and the hydrazine-fluorine would produce the smallest. The high density of the solid propellants offers a decided advantage in reducing the size of the vehicle. Note that the RP-1 - O_2 and the future solid-propellant vehicles weigh more than one million pounds. In contrast the high-energy propellants reduce this weight to approximately 500,000 pounds, about twice the weight of the current ICBM's. There does not appear to be a great difference in size or weight between the hydrazine and the hydrogen vehicles. In such cases the propellant would be selected on criteria other than weight and bulk.

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Summary of Satellite Mission

A 20,000-pound load can be placed in a satellite orbit with vehicles having gross weights from two to five times greater than those of the largest missile today, using the propellants and design values selected. For this mission more handling and operating problems can be tolerated, if necessary to gain performance advantages, than for the surface-to-surface missions.

4793-I

MOON MISSIONS

Moon Circumnavigation without Load Recovery

Figure 18 is a trajectory of a moon circumnavigation. Departing from the earth requires a velocity of about 35,000 feet per second. If the guidance and timing are right, the space craft will approach the moon and be attracted by its gravitational pull. The corresponding numbers on the trajectory and moon orbit give relative positions of the space craft and moon. If correctly timed, the space craft will swing about the moon and turn back toward the earth. If the load is to be recovered, the satellite must be decelerated about 10,000 feet per second to swing into an earth satellite orbit and eventually be slowed by air braking and recovered. The moon circumnavigation with the load not recovered is first considered.

Weight comparisons. - The velocity of 35,000 feet per second required to leave the earth can be obtained with any of the five propellant combinations with the vehicle weights shown in figure 19. The gross weight needed to deliver each pount of payload is given on the ordinate. For example, a vehicle using RP-1 - O_2 has a gross weight - load ratio of 165. A 1000-pound load would require a 165,000-pound gross weight. The trend in weight ratio for the other propellants is very similar to that shown previously for the ICBM mission and the satellite mission; that is, H_2-F_2 has the lowest weight ratio and the present-day solid, the highest. For the high-energy liquids the gross weight - load ratio for H_2-F_2 is about one-third less than that for N_2H_4-F_2. The weight ratio for the present-day solid propellant can be reduced by more than half with the future solid propellant, provided the high specific impulse and lower casing weight assumed for the future solid can actually be realized.

The vehicles using solid propellants are three-stage vehicles, while those using liquid propellants are two-stage vehicles. If three stages were used with RP-1 - O_2, the gross weight - load ratio would be reduced by more than one-third, from 165 to 102.

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4793-I

<u>Effect of changes in specific impulse and component weights used in analysis</u>. - The weight ratios used in the analysis were based on the body weights, engine weights, and values of specific impulse previously given. In addition, an initial acceleration of 1.5 g's was assumed. If these parameters were to vary, the resulting weight ratios would also change.

The effect of a change in specific impulse is shown in figure 20 for H_2-F_2. A 10-percent decrease in effective specific impulse of the first-stage powerplant for the moon mission causes a 33-percent increase in gross weight - load ratio, quite a drastic change. The same trend holds for the second-stage engine and, if the specific impulse of both stages is changed, the effects are combined.

Figure 21 shows the effect of changing engine or powerplant specific weight. For the booster stage of the same mission, a 10-percent increase in powerplant weight causes only a 1.4 percent increase in the gross weight - load ratio.

Figure 22 shows the effect of changing the body specific weight for the same mission. A 10-percent increase in body weight increases the gross weight - load ratio 5.6 percent.

From the foregoing results, the factor affecting the gross weight - load ratio the most is specific impulse; changes in powerplant and body specific weights have a much lesser effect. The magnitudes of the effects depend on the severity of the mission propulsion requirements.

Moon Circumnavigation with Load Recovery

Now consider the requirements for circumnavigating the moon and returning to a satellite orbit about the earth. An initial velocity of 35,000 feet per second is required to leave the earth's surface and an additional 10,000 feet per second to decelerate for entering the earth satellite orbit. This additional velocity can be provided by adding another stage. Note that the solid-propellant vehicles now have four stages and the liquid-propellant vehicles have three stages.

Figure 23 compares the vehicle weight ratios required for this moon mission. With RP-1 - O_2, the gross weight - load ratio is 650. This is four times the weight ratio (165) that was needed to get the load around the moon. This large increase is due primarily to the fact that the additional stage (both propellant and structure) as well as the load must now be propelled around the moon.

The trend in weight ratios for the other propellants is similar to that shown for the moon mission without load recovery. H_2-F_2 again requires the smallest weight ratio and the present-day solid propellant, the highest.

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Moon Satellites and Landing on the Moon

Assume that the problem of establishing an earth satellite platform has been mastered. The platform has been put there by perhaps several trips of vehicles with weight ratios previously described. Assume further that the space platform is orbiting about the earth at a velocity of 25,000 feet per second. Figure 24 shows a mission of a moon satellite departing from and returning to an earth satellite platform. The space craft leaves the earth satellite by increasing the velocity to 10,000 feet per second more than the platform velocity. As the craft approaches the moon, it is decelerated 2200 feet per second to swing into a moon orbit. When the space craft is ready to leave the moon's orbit, the velocity is increased by 2200 feet per second and it turns toward the earth. As it approaches the earth, the space craft must decelerate 10,000 feet per second to swing into an earth satellite orbit and contact the satellite platform. The velocity requirement for this mission is about 24,400 feet per second in addition to that needed to establish the platform.

4793-I

An even more ambitious mission is a landing on the moon and return to the earth satellite platform. Figure 25 shows exactly the same steps as outlined for a moon satellite, except that for the moon landing and takeoff, landing of the moon satellite requires a deceleration of 5700 feet per second and takeoff from the moon's surface to the moon orbit, an acceleration of 5700 feet per second. These velocity requirements total 35,800 feet per second above that of the earth satellite. This is about the same velocity requirement as described for the moon circumnavigation mission.

Figure 26 shows the vehicle weight comparison for a moon landing and return. As an example, the gross weight - load ratio of the RP-1 - O_2 vehicle is only 65 as compared with 165 for the moon-circumnavigation mission requiring about the same velocity. There are several reasons for this difference. The first and most important reason is that three stages are used for this mission instead of the two stages for the moon circumnavigation. Secondly, in launching from a space platform, the specific impulse in large-area-ratio nozzles is appreciably higher than in launching from the earth's surface (see fig. 2). Finally, in launching from a space platform, there are no drag losses such as those encountered in starting from the earth.

These relatively low gross weight - load ratios can, however, be somewhat deceiving. The H_2-F_2 vehicle is chosen to illustrate this point because it has the lowest gross weight - load ratio (24). To get a 10,000-pound load off the space platform, landed on the moon, and back to the platform requires a gross weight of 240,000 pounds. This is about the weight of a present-day ICBM. However, to get these 240,000 pounds to the platform in the first place with H_2-F_2 would require a minimum initial gross weight of about 5 million pounds. If this same

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mission were to be accomplished with RP-1 - O_2 instead of H_2-F_2, then instead of 5 million pounds, an initial minimum gross weight of over 40 million pounds is required.

SUMMARY

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Propulsion requirements for the various missions have been given with selected component weights and the effect of variation in the component weights has been shown. The values given should be used more as illustrations of the trends rather than as proposed designs.

Figure 27 summarizes the propulsion requirements for the missions. Gross weight - load ratio, on a logarithmic scale, is shown as a function of velocity requirement in feet per second. The velocity represents the energy needed to accomplish the various missions. The ICBM, for example, requires a little over 23,000 feet per second; the earth satellite, about 25,000 feet per second; moon circumnavigation, 35,000 feet per second; moon circumnavigation and return, 45,000 feet per second; moon satellite, about 49,000 feet per second; and moon landing and return, about 61,000 feet per second. The upper curve is for RP-1 - O_2 or future solids and the lower curve is for H_2-F_2, representative of the high-energy liquids. The numbers on the curves refer to stages; the curves are really a minimum envelope of several curves of constant number of stages. For missions such as the ICBM or even earth satellites, the gross weight - load ratios for present propellants and high-energy liquid propellants differ by a factor of only 1.5 to 2. However, as the energy requirement becomes greater, the advantages of high-energy propellants are very significant. For the moon landing and return, the ratios differ by a factor of 8. For large payloads and extreme missions, the advantages of high-energy propellants are quite obvious.

There are many problems in the storing, handling, and operation of the various propellants, particularly the cryogenic fluids, that have barely been touched. The potentialities of chemical rockets using liquid and solid propellants have barely been tapped, and the need for intensive research and development in this area is clearly indicated.

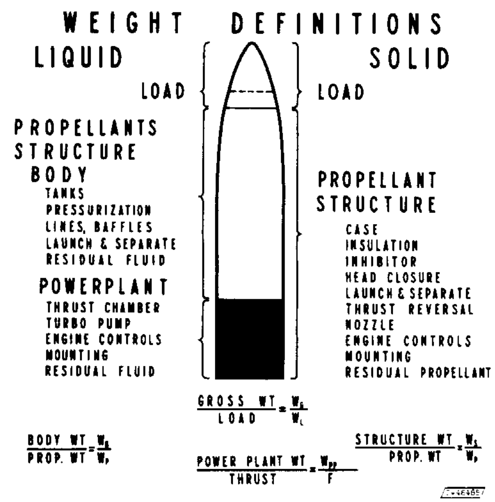


Figure 1

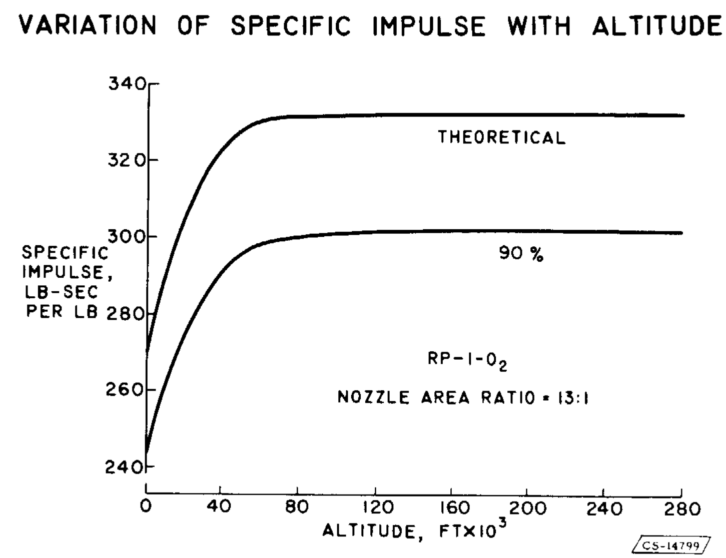
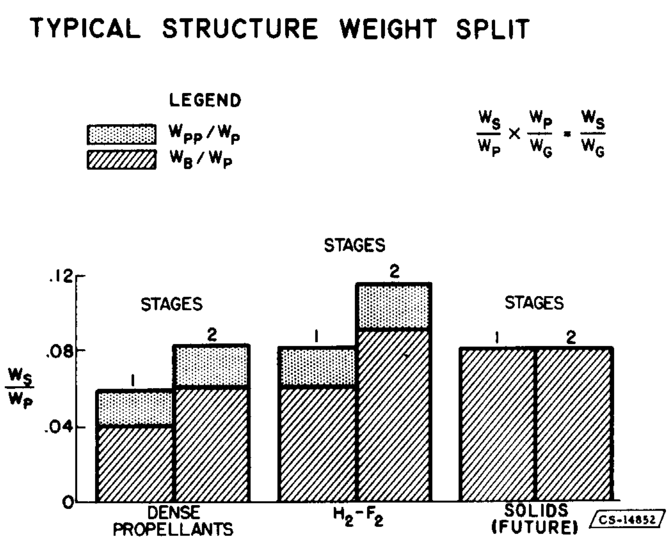


Figure 2



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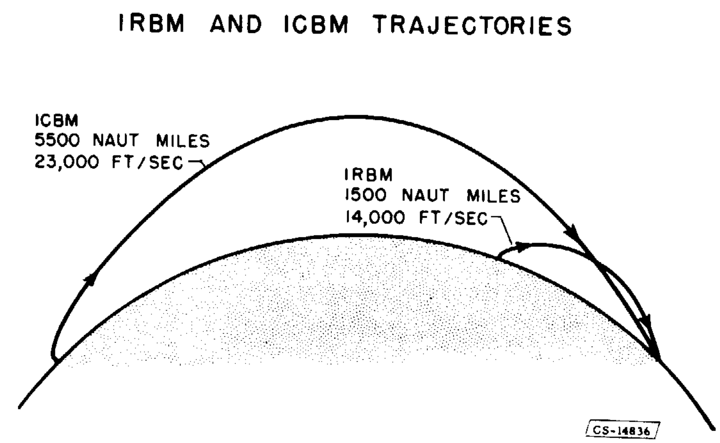
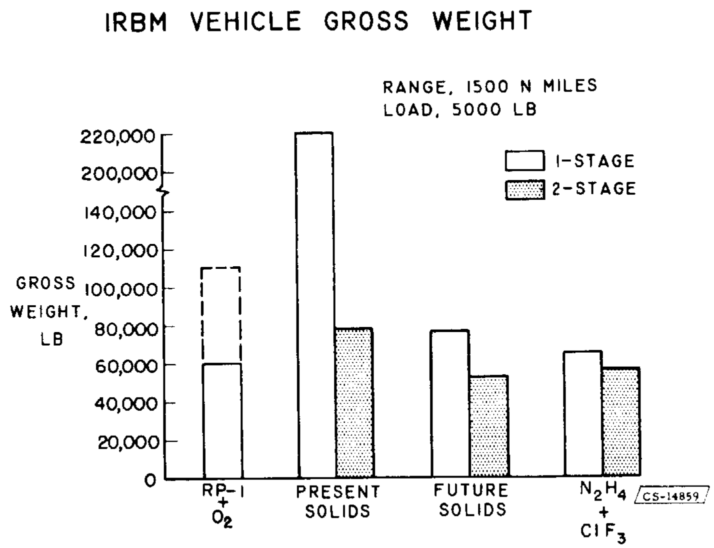


Figure 4

4793



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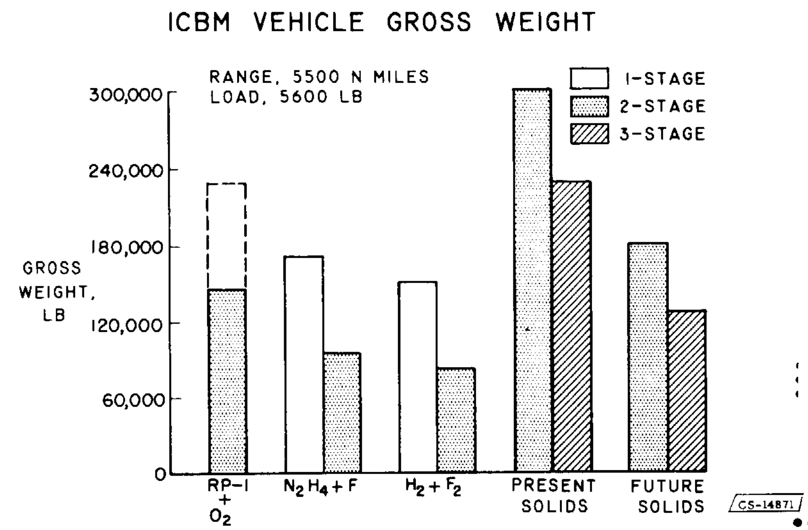

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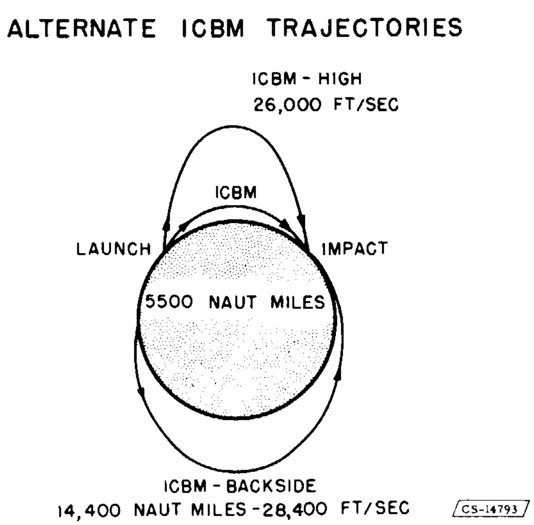

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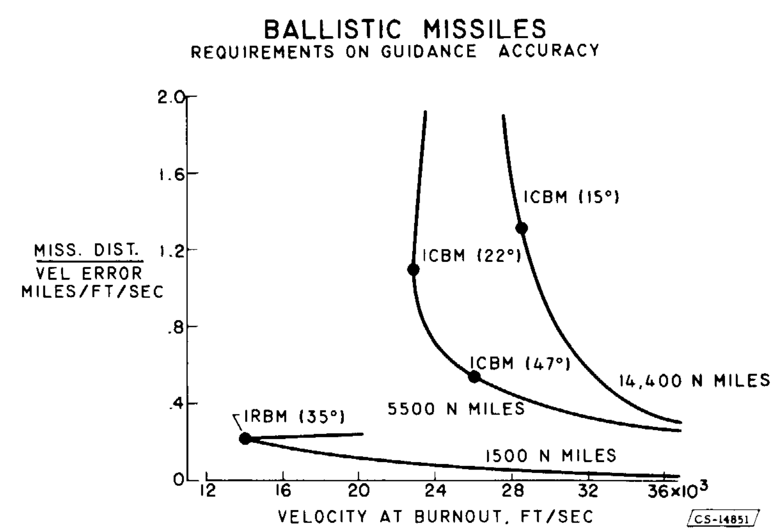

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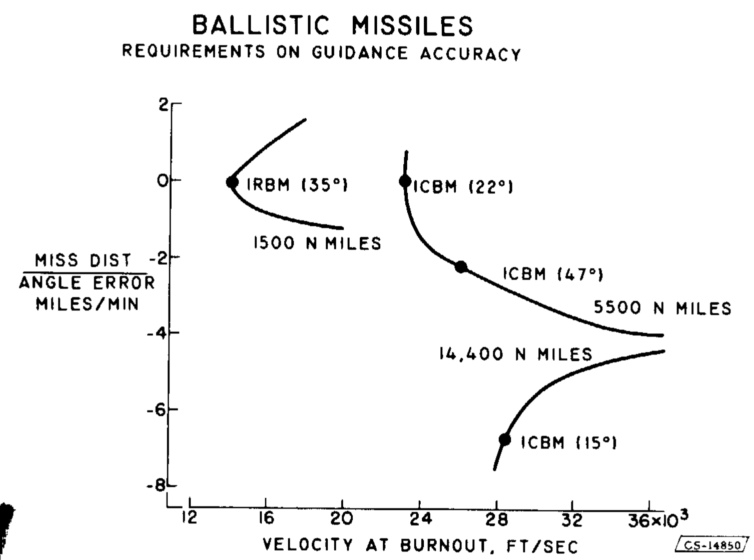

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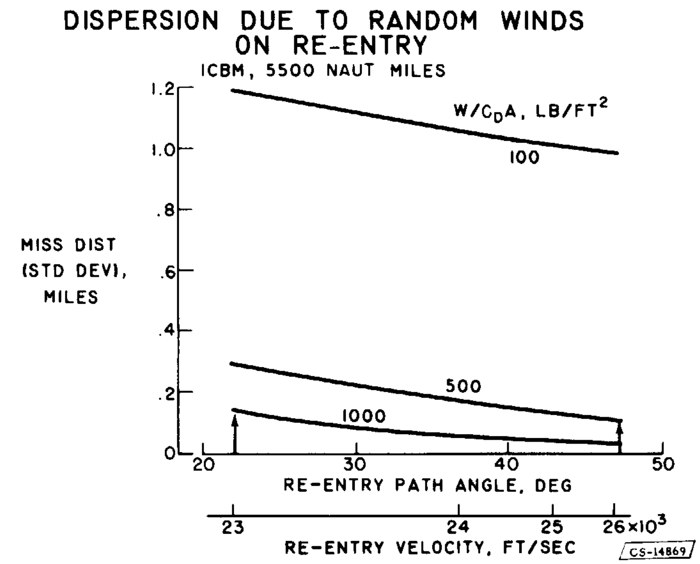

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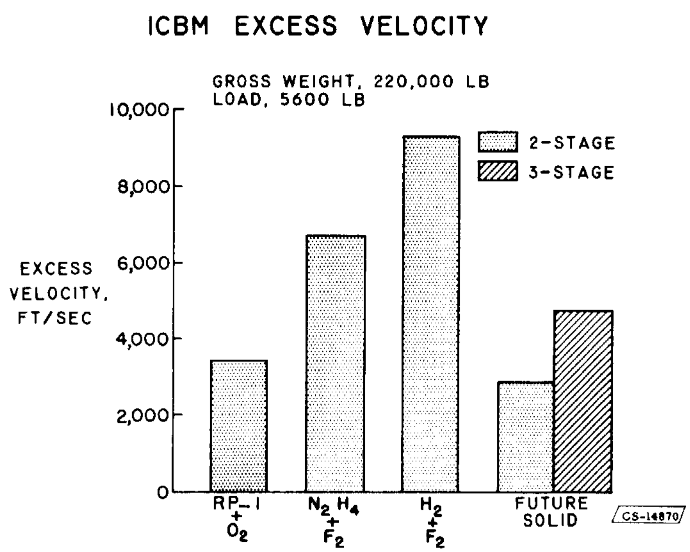

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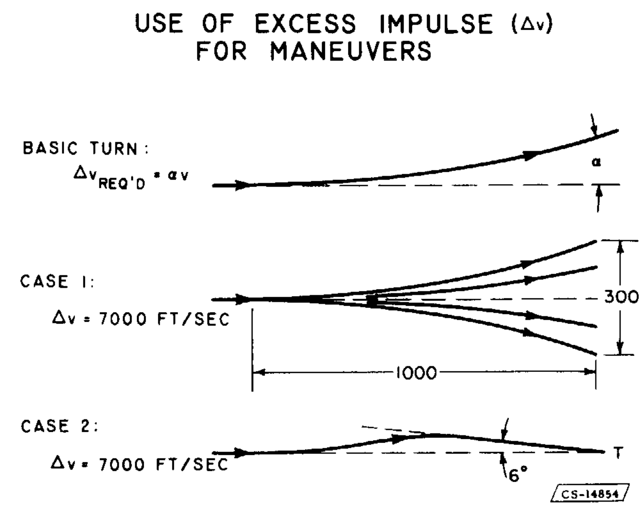

Figure 12

4793

SATELLITE ORBITS

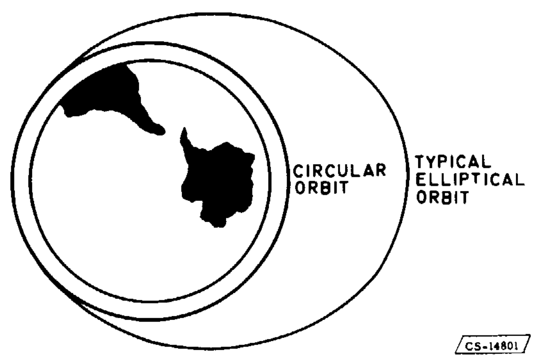

Figure 13

TYPICAL SATELLITE TRAJECTORY

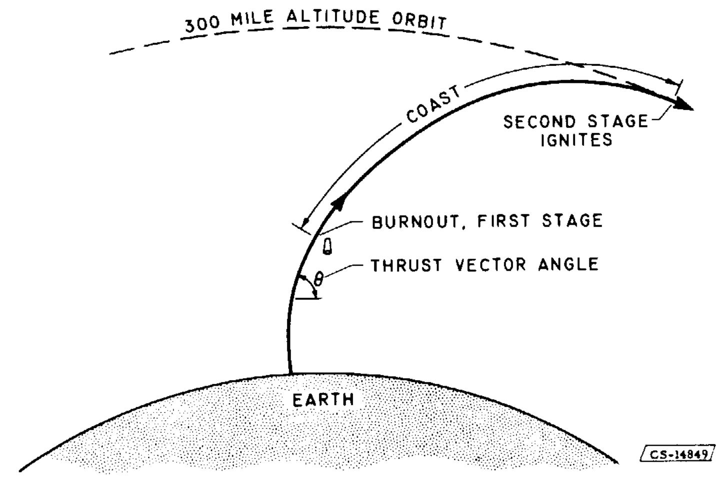

Figure 14

SATELLITE

REQUIREMENTS ON GUIDANCE ACCURACY

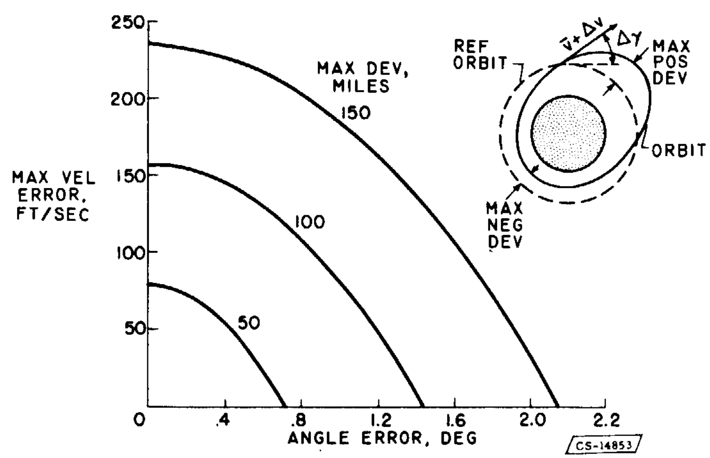

Figure 15

VEHICLE WEIGHT COMPARISON MANNED SATELLITE MISSION

2-STAGES

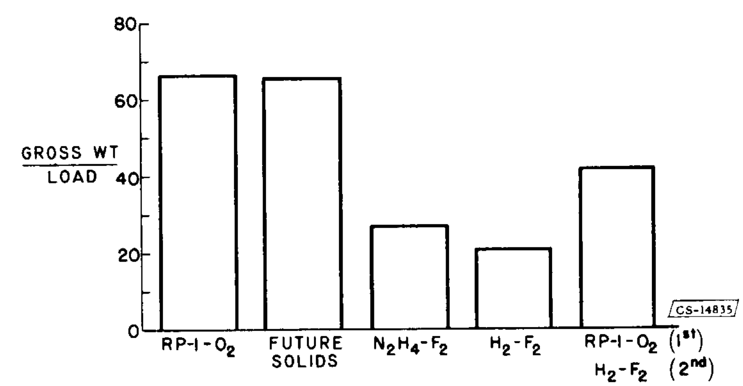

Figure 16

COMPARATIVE SIZE AND WEIGHT OF MANNED SATELLITE VEHICLES

2 - STAGE

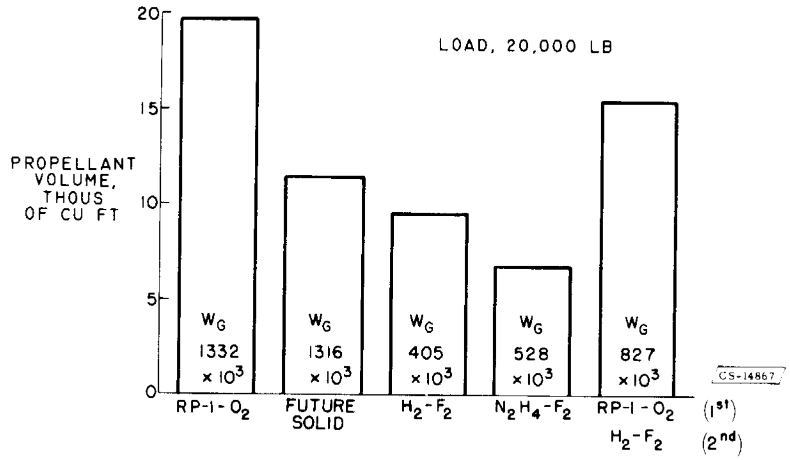

Figure 17

MOON MISSIONS

DEPARTURE FROM EARTH SURFACE

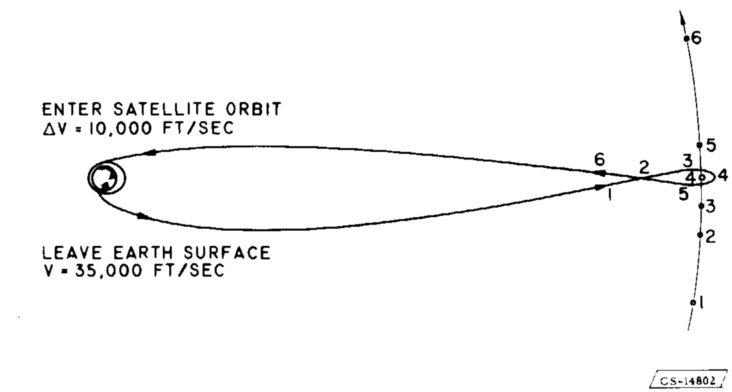

Figure 18

VEHICLE WEIGHT COMPARISON, MOON MISSION

CIRCUMNAVIGATION, LOAD NOT RECOVERED

VELOCITY REQUIREMENT: 35,000 FT/SEC

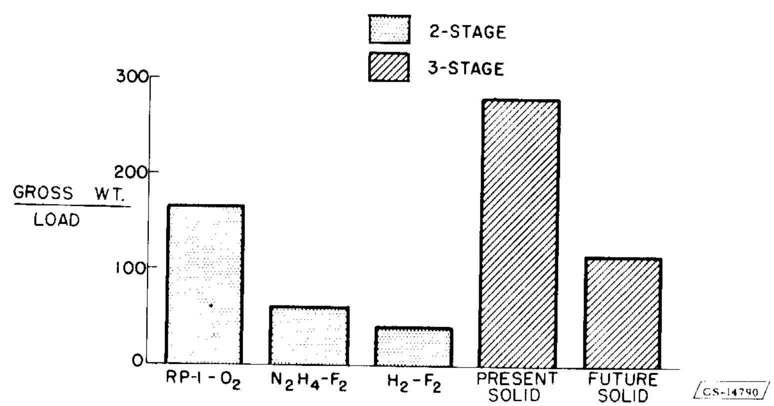

Figure 19

EFFECT OF SPECIFIC IMPULSE

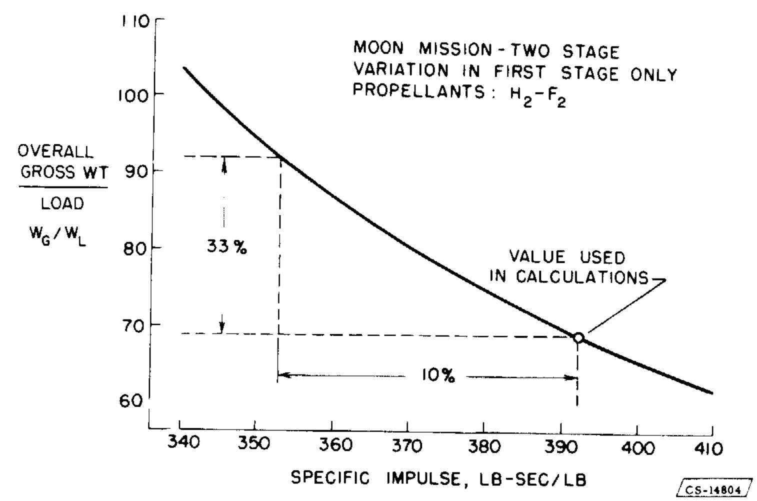

Figure 20

EFFECT OF CHANGING ENGINE SPECIFIC WEIGHT

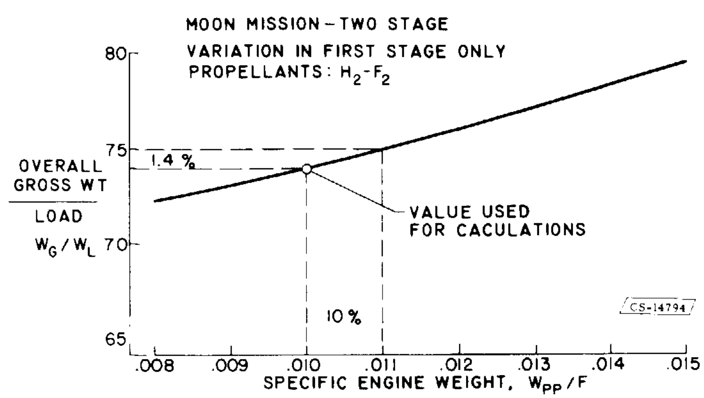

Figure 21

EFFECT OF CHANGING BODY SPECIFIC WEIGHT

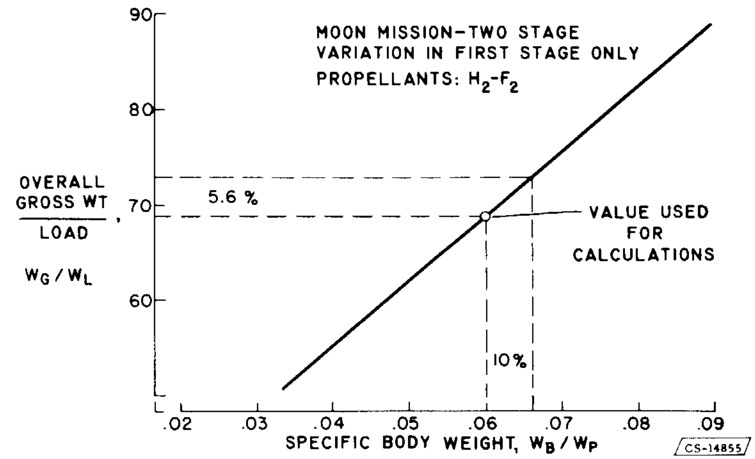

Figure 22

VEHICLE WEIGHT COMPARISON, MOON MISSION

CIRCUMNAVIGATION AND RETURN TO EARTH SATELLITE

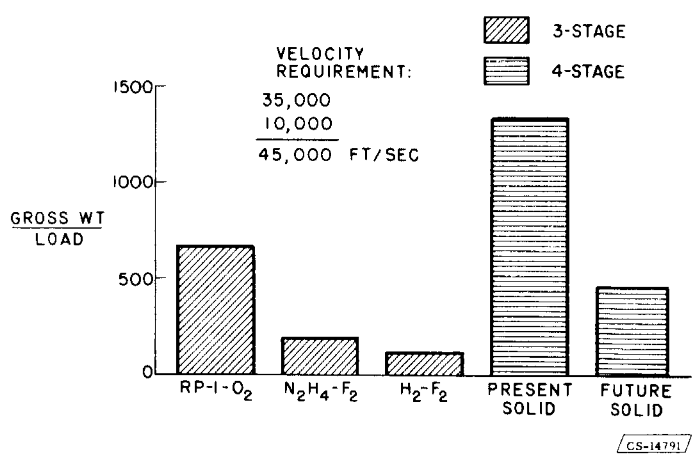

Figure 23

MOON SATELLITE

DEPARTURE FROM EARTH SATELLITE PLATFORM

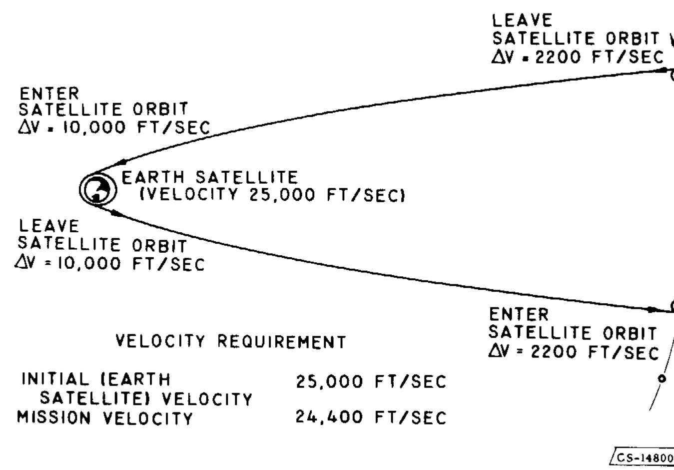

Figure 24

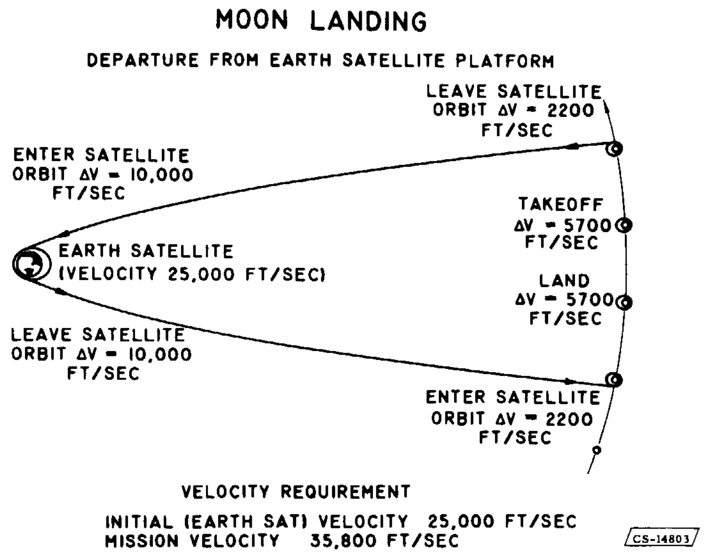

Figure 25

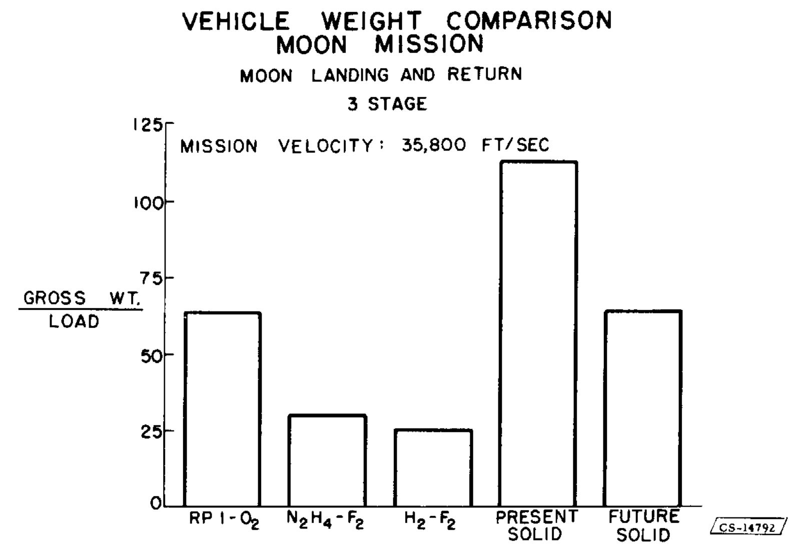

Figure 26

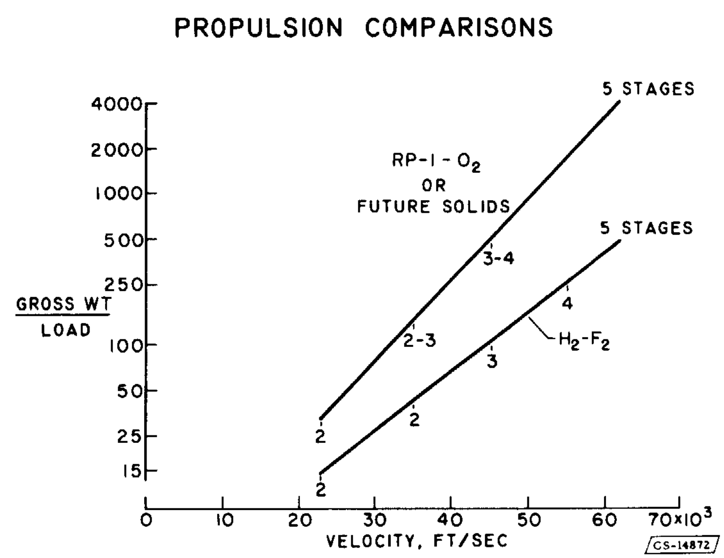

Figure 27